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**TESTING THEORIES OF ECONOMIC FLUCTUATIONS AND
GROWTH IN EARLY DEVELOPMENT**
(the case of the Chesapeake tobacco economy)*

Rafael Flores de Frutos
Instituto Complutense de Análisis Económico
Universidad Complutense
Campus de Somosaguas
28223 Madrid
Alfredo M. Pereira
University of California, San Diego

ABSTRACT

This paper suggests a general econometric approach to the empirical testing of the staple theory. The methodology is based upon a multivariate stochastic time series analysis adjusted to accommodate the presence of co-integration. Consistent with the nature of the problem under consideration, the methodology does not require any a priori structural assumptions about the dynamic relations among relevant variables. The empirical part of the paper focuses on the dynamic relationships among tobacco prices in the colonial Chesapeake economy and tobacco demand and supply conditions. The empirical evidence gives strong support to the basic tenets of the staple theory: the central role of the exogenous British demand; the existence of fluctuations in the price of tobacco; and, the high responsiveness of tobacco production with respect to prices relative to tobacco demand.

RESUMEN

Este artículo sugiere un enfoque econométrico general, al problema empírico de contrastación de la teoría de la cosecha. La metodología se basa en el análisis multivariante de series temporales, adaptado para tratar adecuadamente la presencia de cointegración. Consistente con la naturaleza del problema en cuestión, la metodología no requiere supuestos estructurales a priori acerca de las relaciones dinámicas entre las variables relevantes.

La parte empírica del artículo se concentra en las relaciones dinámicas entre los precios del tabaco, en la economía colonial del Chesapeake, y las condiciones de demanda y oferta. La evidencia empírica apoya las tesis básicas de la teoría de la cosecha: El papel central y exógeno de la demanda británica de tabaco, la existencia de fluctuaciones en el precio del tabaco y la alta sensibilidad a los precios de la producción frente a la demanda de tabaco.

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I. Introduction

The staple theory has informed most of the work on export-led growth and, in particular, on the economics of colonial development. This thesis attaches fundamental importance to the export sector in the process of colonial development. There is an export crop which is central to the development of the region. Foreign demand for this crop, which is exogenous to the region, plays a central role in the economic mechanisms behind both long term growth and shorter run economic fluctuations (see Galenson and Menard, 1980, for a comprehensive view of this theory).

Empirical tests of the staple theory are scant. First, the test of competing theories and the use of structural analysis supposes a number of priors about the dynamic functioning of the colonial economies, which are difficult to establish. Second, the full evidence needed to test the theory for many regions and different periods is still to be collected, so a meaningful statistical approach to determine the most adequate economic model is not available. An important exception to this situation is the case of the tobacco economy in colonial British America (see Gray, 1941, North, 1961, and Sheridan, 1974, for other exceptions).

This paper suggests a general econometric methodology to allow the empirical testing of the staple theory. The methodology puts together several recent developments in the theory of time series analysis, namely on the development of multivariate stochastic time series techniques adjusted to accommodate the presence of co-integration as well as on the diagonalization of the matrix of contemporaneous correlations of the residuals of the multivariate model. This approach, which is very general in nature, is uniquely

appropriate to analyze theories of early development in that it does not require any a priori structural assumptions about the dynamic relations among relevant variables.

The empirical methodology is implemented to the case of the tobacco economy in colonial British America. Tobacco unquestionably dominated economic life in the colonial Chesapeake. Accordingly, the prevailing explanation of both global economic growth and short-run economic fluctuations are in the vein of the staple theory with the tobacco economy in the leading role. Menard (1980, 1985) suggests that during the seventeenth century improvements in the supply of tobacco provided the principal engine of growth as greater output, lower risks, more efficient distribution, and increased productivity forced tobacco prices down and widened the market for the crop. In the eighteenth century, Clemens (1980) and Kulikoff (1979) suggest that demand for tobacco provided the principal driving force for growth as higher prices absorbed increased costs and induced planters to expand.

Simultaneously, there is abundant evidence that long-run growth process in the colonial Chesapeake was accompanied by a sequence of periods of prosperity and depression (see for example, Gray, 1941, Clemens, 1980, and Menard, 1980 and 1985). The boom and bust hypothesis, coined by Earle (1975), attempts to explain economic fluctuations within the long run periodization of the Chesapeake economy. The central role in this theory is played by fluctuations in tobacco prices induced by changes in foreign demand. These fluctuations in tobacco prices reverberated through the economy. High tobacco prices induced investment in land and labor and led to an expansion of production. Since demand, however, was inelastic relative to supply, planters would overproduce, thereby generating falling tobacco prices. A depression would follow the boom. The two critical assumptions of the boom and bust hypothesis are the existence of regular fluctuations in the price of tobacco due to changes in the British demand of tobacco and the relatively high responsiveness of tobacco production to tobacco prices, vis-a-vis British demand.

The earliest empirical evidence on the staple theory as applied to the tobacco

economy and on the boom and bust hypothesis was developed by Clemens (1980) and Menard (1980, 1985). The colonial Chesapeake economy is characterized by two long periods of growth from the 1620's to 1680's and from around 1715 to 1775 surrounding a shorter period of stagnation. Within each period, the evolution of tobacco prices is studied to determine price trends. Regression residuals around such trends are interpreted as indicators of economic fluctuations in tobacco prices. In turn, fluctuations in tobacco prices are used to explain economic cycles. The conjecture that tobacco production is more responsive to changes in tobacco prices than is British demand for tobacco is not tested due to the absence of tobacco production data.

The empirical results in Clemens (1980) and Menard (1980, 1985) as well as the main tenets of the boom and bust theory were challenged by Wetherell (1984). Wetherell (1984) argues first, that tobacco prices exhibit no detectable cycles, but a behavior best described as a simple random walk, and second, that the production of tobacco was fundamentally inelastic. Accordingly, Wetherell (1984) suggests that the boom and bust theory should be rejected.

More recently, Pereira (1991) provides empirical evidence on fluctuations in the price of Chesapeake tobacco and on the economic variables that help predict tobacco prices. The most important point in Pereira (1991) is that the data confirms statistically the dependence of tobacco farm prices on British demand of tobacco, as suggested by the boom and bust proponents. Accordingly, one-dimensional tests of boom and bust (like those in Clemens, 1980, Menard, 1980 and 1985, Wetherell, 1984, and Pereira, 1991), are hardly appropriate and conclusive. Considerations of dynamic relations and feedbacks among the relevant economic variables must be in the center of the analysis.

The multivariate stochastic time series approach suggested in this paper is implemented to analyze the mechanisms of long term-growth and short-run fluctuations in the Chesapeake tobacco economy for the period 1676-1713. We find strong empirical evidence in favor of the view of the staple theory on the leading role of British demand for

colonial tobacco exports. In addition, empirical evidence strongly supports the two key assumptions of the boom and bust hypothesis. First, this paper shows that Chesapeake tobacco prices do follow a random walk, but, a simple univariate time series analysis is not enough to conclude that tobacco prices exhibit no detectable cycles. A deeper analysis of the relationships among tobacco prices, British demand of Chesapeake tobacco, and the price of land, reveals the existence of cyclic responsiveness in tobacco prices to variations in the British demand. Second, the paper argues that British demand for tobacco is inelastic with respect to Chesapeake tobacco prices, which supports the assumption of higher responsiveness of tobacco production to tobacco prices. In this analysis a proxy is proposed for the rate of change of desired production of tobacco. This variable responds positively to the rate of growth of tobacco prices. Changes in this variable, however, do not seem to affect the rate of growth of British demand.

II. The Econometric Approach

The methodology suggested here to deal with the general issue of the empirical testing of the staple and boom and bust theories combines recent developments in the area of building multivariate stochastic ARMA models in the presence of co-integration and the diagonalization of the matrix of contemporaneous correlations of the estimated residuals.

The development of statistical methods to integrate economic theory with time series analysis has long been a major concern of both economists and statisticians (see Zellner and Palm (1974) for an important contribution to the renewal of this concern). For a long period econometric models were not regarded as neutral statistical instruments to help economists choose among competing economic theories. Serious deficiencies in their dynamic specification detracted from their reliability. Also, data sets are typically too aggregated, too short, or too contaminated by random noises to provide enough information to discriminate among competing statistical models. In order to do so

extraneous information from economic theory is often used.

The quest for neutral statistical instruments and proper integration of economic theory and time series data analysis has generated important developments. The multivariate ARMA class of models appears to be among the most neutral instruments to analyze any discrete stochastic time series data set. The claim to neutrality comes from different lines of argumentation. First, the general class of dynamic models accommodates the entire set of linear dynamic relations which may be present in the data set. Second, building a model in this class does not require economic theory constraints. Third, the statistical properties and specific features of individual time series are taken into account.

A complete methodology to build a specific stochastic multivariate ARMA model for a stationary vector of variables has been developed (see Jenkins and Alavi, 1981, and Tiao and Box, 1981, for comprehensive presentations). An iterative procedure of identification, efficient estimation, and diagnostic tests guarantees that the final specification is the best within the general class of multivariate stochastic ARMA models.

As most economic series show non-stationarity features, one important complication associated with any time series analysis is the problem of choosing the appropriate order of differentiation. This is especially important in a multivariate framework as over-differentiation may lead to inefficient and unnecessarily complex models (see Box and Tiao, 1977). In a multivariate framework, the most serious problem of over-differentiation has to do with the presence of non-stationary common factors. Common factors and their treatment in order to simplify the structure of the stochastic model has long been recognized as a fundamental issue (see Quenouille, 1957, pioneering work and more recent contributions by Pena and Box 1984 and 1987, Stock and Watson, 1988, Tsay and Tiao, 1986, and Tiao and Tsay, 1989).

The most popular case of common factors is the case of non-stationary common factors, referred to as co-integration (see Granger, 1981 and 1986, and Engle and Granger, 1987, for seminal contributions). The analysis of co-integration has shed light on how to

simplify the dynamic structure by reducing the dimension of the non-stationarity problem.

Pena and Box (1987) show how, in the presence of stationary common factors, a linear transformation of the original stationary vector can be used in order to simplify the underlying structure of the observed series. Pena (1990) extends this result to the case of non-stationary common factors present in a vector of non-stationary time series.

Treadway (1990) suggests a procedure to build a multivariate ARMA model from a vector of $I(1)$ variables, where co-integration has been detected. In the case of a vector z_t of n $I(1)$ components, where there are r co-integrating relationships, Treadway (1990) proposes to apply the standard Alavi and Jenkins (1981) methodology to a stationary vector z_t^* , which contains the r error correction mechanisms, associated to the r co-integration relationships, along with $n-r$ first differenced variables. The $n-r$ variables to be differenced must be chosen from the elements in z_t . Their choice should allow a meaningful economic interpretation of the variables in z_t^* and should keep the structure of the multivariate ARMA model generating z_t^* as simple as possible.

At this stage of the analysis it is not yet possible to discuss specific economic theories since we have not reached yet a structural model. Rather, we have a purely statistical model which relates each variable in z_t^* to the past values of all the variables in the vector.

Flores (1987, 1989), suggests interpreting the matrix R of contemporaneous correlations among the error terms of the ARMA model as intra-period effects among variables. This interpretation facilitates the transition from the pure statistical ARMA model to a structural representation. If z_t^* contains the variables relevant in the underlying structural model, and the structural equations are assumed to have independent error terms, non-zero correlations among the error terms of the ARMA model can be seen as a consequence of intra-period effects among variables. Thus, to go from the pure statistical ARMA model to a structural representation only requires the diagonalization of R . This can be done by pre-multiplying the ARMA model in its infinite AR representation by a

matrix ν of intra-period effects. Since ν is not unique there is a problem of identification. A unique matrix ν can be obtained by rejecting, on economic grounds, unreasonable matrices of intra-period effects. Accordingly, the reasonability of the economic theory reflected in the structural specification depends on the reasonability of the choice of the matrix ν . The interpretation of the non-identity matrix R as intra-period effects among variables in the structural representation is, therefore, central to the analysis.

According to the discussion above, the approach suggested in this paper can be summarized as follows. First, we perform exploratory data analysis following Box and Jenkins (1976) to study the statistical properties of the individual data series as well as other specific features of the data set (see Box and Tiao, 1975, for a treatment of extreme observations through intervention analysis). The models elaborated at this stage can be used as a benchmark to judge the performance of more elaborated models. Second, we apply the methodology of Jenkins and Alavi (1981) to build a multivariate stochastic ARMA model for a vector of stationary variables. This vector contains the original variables in z_t , differentiated as indicated by the corresponding univariate models (typically, first differences are required for stationarity with yearly data). Third, if co-integration relationships are present in the original vector of variables, over-parameterization and non-invertibility problems will occur in the previous step. Formal testing procedures and estimation of the co-integrating vectors can be carried out following Engle and Granger (1987). If co-integration occurs, the vector of variables should be transformed according to Pena (1990) and Treadway (1990). Now, the methodology of Jenkins and Alavi (1981) can be applied to the new stationary vector of variables. This procedure allows determination of the most likely and the simplest multivariate stochastic ARMA generating model. Fourth, upon determination of the most adequate multivariate stochastic ARMA model we suggest, following Flores (1987, 1989), diagonalizing the matrix of contemporaneous correlations of the error terms according to their interpretation as intra-period effects. The choice of a particular matrix of intra-period effects allows us

to obtain the corresponding structural representation. The final step consists of estimating the structural model equations.

III. The Chesapeake Tobacco Economy: Data Set and Variable Definitions

Proponents of boom and bust have insistently discussed the importance of demand conditions and the conditions surrounding tobacco production, in particular, the prices of labor and land inputs in the determination of tobacco prices. Accordingly, to examine the dynamic interactions that determine the evolution of tobacco prices (PT), we consider as potential relevant variables the British imports of tobacco (BDT), the prices of servant (PSE) and slave labor (PSL), as well as the price of land (PLA). (Henceforth, x and \dot{x} denote the logarithm and the logarithmic rate of change of X , respectively.) The following is a brief description of the data sources (the data sets are available from the authors upon request).

The farm prices in Pence Sterling per pound of tobacco for the period 1616–1730 are published in Menard (1980, 1985). The series refers to Maryland and Virginia tobacco for the years 1616–1658 and only to Maryland thereafter. The original published sources are: for the years 1616–1658, Menard (1976); for 1659–1710, Menard (1973); for 1710–1719, Menard (1985); and, for 1720–1730 new probate inventories for the Western Shore of Maryland together with Clemens (1980) from Talbot county inventories. Additionally, Clemens (1980) provides a tobacco price series for Maryland (Talbot and Kent Counties) for the period 1680–1774.

The prices in constant Pound Sterling of servant labor are taken from Menard (1977). The period covered is 1641–1720. The prices in Pound Sterling at Barbados of slaves are taken from Galenson (1982). The period covered is 1673–1723. The median land prices in pounds of tobacco per acre for the period 1663–1699 in Maryland are reported in Wyckoff (1935). This series is extended until 1720 by Clemens (1980).

British imports of Chesapeake tobacco in Pounds are obtained from Menard (1980). The period covered is 1616–1730. This data series is consistent with the series originally published for the period 1708–1792 by Price (1973). Menard's series reflect both English and Scottish imports. Pereira (1991) argued that British imports of tobacco should be interpreted as essentially reflecting demand conditions. Therefore, British tobacco imports will be referred to below as British demand for tobacco.

This paper focuses on the evolution of the price of Chesapeake tobacco and its relation to other economic variables in the period 1676–1713. Clemens (1980) and Menard (1980, 1985) subdivide the colonial period in the Chesapeake economy into three different stages. Our data covers the intermediate stage, which is characterized by these authors as a homogeneous phase of development. Sufficiently large data sets for the relevant variables for the earlier and later periods are not available. At any rate, any attempt to obtain estimates for long periods without taking into consideration structural breaks seems inadequate. Indeed, there are several reasons to believe that the underlying economic structure changes substantially throughout the colonial period (1616–1776). The growth mechanisms are substantially different in the seventeenth and eighteenth centuries (see Clemens, 1980, and Menard, 1980). There are fundamental changes in the use of labor inputs from servants to slaves (see Menard, 1977). The significance of the production of grain in the development of the tobacco colonies changed in the later colonial period (see for example Klingaman, 1969). The role of Scotland in the tobacco trade and financing mechanisms of the colonial production evolved throughout the period (see Price, 1954).

IV. The Chesapeake Tobacco Economy: Empirical Analysis

In this section we apply the methodology introduced in Section II to the data described in Section III.

A. Univariate and intervention analyses

Table 1 reports the results of the univariate analysis as in Box and Jenkins (1976) and intervention analysis as in Box and Tiao (1975). All variables, except for pse , are integrated log-normal variables of order 1, $I(1)$, i.e., they must be differenced once to achieve stationarity. The price of servants, which is not included in Table 1, behaves as a non-stochastic variable, i.e., it changes level only a few times over the sample period. Therefore no univariate model was built for this variable and it is omitted in the subsequent analysis.

As Table 1 shows, bdt has two important extreme values (three standard deviations) in 1703 and 1705. These values make the asymmetry and kurtosis coefficients assume high values. Intervention analysis shows that those observations can be modeled with an impulse variable, implying that they represent transitory mean level departures. After intervention analysis, the asymmetry and kurtosis coefficients assume values consistent with normal distribution (-0.36 and 3.54 respectively).

Furthermore, the estimation of the different univariate series suggests that pt follows a random walk process, as suggested in Wetherell (1984), while bdt , pl , and psl are $IMA(1,1)$ processes.

The cross correlation functions among the univariate residuals on these series show that residuals of psl are not correlated at any lag with any of the remaining variables. In order to keep the system as simple as possible, this variable is omitted in the subsequent analysis. In fact, experiments were conducted in which this variable was included in the final specification of the ARMA model, as obtained below. The results of this experiment, which are not reported here, confirm that this variable does not affect the remaining variables in the model.

B. Building the multivariate stochastic ARMA model

The objective is to study the dynamic relationships among British demand of tobacco, tobacco prices, and the price of land using the methodology in Jenkins and Alavi (1981) to generate the multivariate stochastic representation. Let the residuals of the univariate stochastic models be denoted by a_{bt} , a_{pt} , and a_{lt} , for bdt , pt and pl , respectively. The cross correlation functions among these residuals indicate that a_{pt} is uncorrelated with either a_{bt+j} or a_{lt+j} ($j>0$); that a_{lt} is uncorrelated with a_{bt+j} or a_{pt+j} ($j>0$); and that a_{bt} is correlated with a_{lt+1} .

Given the structure of the ARMA specification, the univariate models for bdt and pt do not have to be re-estimated. An efficient estimation of the dynamic relationship between pl and bdt indicates that these variables could be co-integrated:

$$pl_t = \begin{pmatrix} .04 \\ .11 \end{pmatrix} + \begin{pmatrix} .21B \\ .11 \end{pmatrix} bdt_{t-1} + \begin{pmatrix} (1-.94B) \\ (.06) \end{pmatrix} a_t$$

The moving average parameter in the noise of this equation is close to one, indicating a possible relationship of stationarity between pl and bdt .

C. Testing for the presence of co-integration

Co-integration between pl and bdt is tested using procedures suggested by Engle and Granger (1987). As shown in Table 2, the presence of co-integration is confirmed. In fact, the coefficient associated to the error correction mechanism (henceforth ECM) lagged one year is statistically different from zero. The possibility of a second co-integrating relationship has been tested and rejected.

The price of land and the British demand of tobacco, $I(1)$ variables, are co-

integrated. As pl does not seem to cause (in the sense of Granger, 1980) bdt , there seems to be a positive long term relationship from bdt to pl . Movements of these variables away from their equilibrium values have a transitory character. This feature seems reasonable if we think of land as being the main storage of wealth in colonial British America. Increases in bdt should be associated with greater benefits for tobacco producers and greater increases in the demand for land and consequent increases in land prices.

Following Treadway (1990), the Jenkins and Alavi (1981) procedure can now be applied to the a modified vector of variables. This new vector of variables, which takes into consideration the presence of co-integration, includes ECM instead of the pl .

The final multivariate stochastic ARMA model is summarized in Table 3a. It is an ARMA(1,1) representation which displays a particular dynamic structure. The rate of growth of the price of tobacco pt does not receive lagged effects from either ECM or bdt . Also, the rate of growth of British demand of tobacco bdt does not receive lagged effects from the other variables. Only ECM receives effects from other lagged variables, i.e., from pt_{t-1} . However, important contemporaneous correlations among the components of the noise vector are detected (more on this below).

Tables 3b-3d. show the most important information pertaining to the diagnosis stage. Table 3b. shows the mean, standard deviation, asymmetry and kurtosis coefficients as well as possible extreme values associated with the residuals. Table 3c. shows the simple (acf) and partial (pacf) autocorrelation functions of the residuals. Finally, Table 3d. shows the cross correlation functions (ccf) among residuals as well as the contemporaneous correlations.

D. Structural analysis

To find the adequate interpretations of the elements of the matrix of

contemporaneous correlations among the components of the noise vector we rule out all possible alternatives (reduction to the absurd). First, the error terms associated with bdt and pt are positively correlated. One possibility is that this is because bdt displays intra-year response to variations in pt . The positive correlation between bdt and pt , however, implies that intra-year increases in the rate of growth of the price of tobacco lead to increases in the rate of growth of British demand, a situation that does not seem defensible on economic grounds. Accordingly, the positive correlation implies that the relation should go from the bdt to pt .

Second, the error terms of ECM and pt are negatively correlated. Suppose the intra-year relation goes from pt to ECM. Then, given the discussion above, pt does not affect bdt and, therefore, increases in pt would be associated to declines in pl and/or increases in bdt . This does not make sense on economic grounds. One would expect increases in pt to be associated with high demand for land and an increase in the price of land. Also, one would expect increases in pt to be associated with either no movements or declines in bdt , not increases. Accordingly, the relation must go from ECM to pt .

Third, the error terms of ECM and bdt are negatively correlated. Suppose ECM leads bdt . Consider an instantaneous and transitory change in bdt . If pl in the ECM remains constant then bdt changes. This change may be transitory or permanent. At any rate, a change in the rate of growth of British demand of tobacco (bdt) has permanent effects on the level of bdt . Either we have reached a contradiction because we have assumed transitory changes in bdt (levels) or we require pl in the ECM to change. In this case, we require pl to change permanently in such a way that the permanent change in bdt (levels) is permanently neutralized. This means, however, that pl leads bdt , which does

not make sense on economics grounds (see discussion of co-integration above).

Accordingly, the relation goes from bdt to ECM.

Given the multivariate stochastic ARMA(1,1) model as determined before and under the interpretation of the intra-period effects as developed above, we can obtain a structural model. Under the above interpretation of the intra-period effects it is possible to find a triangular matrix ν

$$\nu = \begin{bmatrix} 1 & \nu_1 & \nu_2 \\ 0 & 1 & \nu_3 \\ 0 & 0 & 1 \end{bmatrix}$$

such that $\nu a_t = \epsilon_t$, where ν_1 is the contemporaneous effect of ECM on pt , ν_2 is the contemporaneous effect of bdt on pt , ν_3 is the contemporaneous effect of bdt on ECM, a_t is the vector of white noise contemporaneously correlated errors in the multivariate stochastic ARMA (1,1) model, and ϵ_t is the vector of white noise contemporaneously uncorrelated components which corresponds to the error terms of the structural equations.

Once the multivariate stochastic ARMA(1,1) model has been expressed as a pure infinite AR process (by pre-multiplying it by the inverse of the moving average matrix), the structural equations can be obtained by pre-multiplying the autoregressive representation by the ν matrix. In our case, the resulting model shows a recursive pattern: first, pt depends on present and past values of ECM and bdt; second, ECM depends on the lagged values of pt , as well as present and past values of bdt; finally, bdt depends only on its own past values.

As factor cancellation can occur, it is proper to re-estimate the structural model equations now that insights from the economic theory have been incorporated into the analysis. Due to the specific recursive form of the structural model, the tobacco price and

the ECM equations can be re-estimated separately as transfer function models (see Box and Jenkins, 1976). Notice that the British demand equation does not have to be re-estimated since it has already been established that bdt does not receive feedbacks from the other two variables. The final estimated equations of the structural model are presented in Table 4a.

Equation 1 is the price of tobacco equation. In this equation pt depends exclusively on contemporaneous values of ECM and bdt. The noise in this equation follows an AR(2) process with complex roots, which generates a cycle of 6.5 years. Parameterization B in Table 4a, which is merely a different way of writing parameterization A, is especially useful. In fact, it allows us to interpret ECM as a proxy variable for the rate of growth of tobacco production. Following this, pt depends negatively and contemporaneously on a variable which reflects overproduction as suggested by the boom and bust theory.

The interpretation of the ECM as a proxy for the rate of growth of tobacco production can be argued for as follows. Notice that pt can be expressed to depend instantaneously and negatively on the variable $[3.125 \text{ ECM} - \text{bdt}]$. Due to the sign of the coefficient, as well as the specific form of this variable, it can be interpreted as the desired rate of growth of tobacco excess supply. If this variable is accepted as a proxy for the desired rate of growth of tobacco excess supply, then ECM will be a proxy for the rate of growth of tobacco production.

Equation 2 is the tobacco production equation. It relates the rate of growth of tobacco production (ECM) to the rate of growth of tobacco prices lagged one year and to the present and past rates of growth of British demand. The noise in this equation follows an AR(1) process.

At this point it is important to note that due to the specific form of the transfer function associated to bdt in Equation 2, ECM responds slowly and cyclically to variations

in bdt . As pt in Equation 1 responds instantaneously to ECM variations, pt also responds slowly and cyclically to variations in bdt . This, again, confirms the assumptions of the boom and bust theory.

Equation 3 is the British demand equation. It does not depend on either pt or production conditions as reflected by ECM. This confirms the second tenet of boom and bust theory, i.e., that British demand is less responsive to price changes than the production of tobacco, and confirms the central role of exogenous British demand of tobacco as suggested by the staple theory.

Finally, as long as the cycle in prices induced by the cyclical response of ECM to variation in bdt can be partially compensated by the cycle displayed by the noise in Equation 1, univariate analysis of pt is not able to detect cycles but may rather suggest a random walk behavior. Multivariate analysis, however, allows us to uncover the cyclical behavior. This confirms the initial intuition on the limitations of univariate analysis (see Pereira, 1991) and suggests that results in Wetherell (1984), rather than representing a denial of the boom and bust theory, are actually fully consistent with this theory.

Table 4b shows the long term elasticities of production, British demand, and tobacco prices in Equations 1 and 2. It presents the mean, standard deviation, extreme values, asymmetry and kurtosis coefficients corresponding to the residuals in the structural equations. Table 4c. shows the acf, pacf, and ccf of the residuals which confirms the goodness of the fitted models.

E. Impulse responses

To illustrate the dynamic mechanisms in the estimated model, let's assume that after an equilibrium situation in year -1 ($\text{pt} = \text{pl} = \text{bdt} = 0$), bdt experiences an unitary

impulse in year 0 ($\text{bdt}_0 = 1.0$). The impulse response functions for production, excess supply and the rate of growth of land prices and tobacco prices are depicted in Figures 1-4.

In year 0, the variable $[3.125 \text{ ECM} - \text{bdt}]$ takes a negative value of -2.47 reflecting a situation of excess demand for tobacco. This disequilibrium raises pt from 0 to .20. In year 1, the positive pt and the corresponding greater benefits for tobacco producers in year 0 lead these agents to buy land and to produce more. These effects reduce the disequilibrium in $[3.125 \text{ ECM} - \text{bdt}]$, which rises from -2.47 to -1.39 . The excess of demand continues but with less intensity, thus pt decreases from .20 to .11. Now, pl is .24, which is consistent with the idea that land is being demanded during this year. In year 2 the positive pt continues to induce an increase in the production of tobacco as well as the purchase of land and land prices. Thus, $[3.125 \text{ ECM} - \text{bdt}]$ rises again from -1.39 to -1.11 , pt declines from .11 to .09, and pl declines from .24 to .23. This process follows until year 4, when an important change occurs. The increases in production, induced by the (still) positive (.04) pt in year 3, provokes an excess of supply. This overproduction continues growing for two years before starting to decline. This phenomenon can be interpreted as a part of the producers learning process or the need for producers to redeem their land investments. These disequilibria vanish slowly in a cyclical fashion. After approximately 9 years, the rates of growth of the relevant variables have essentially returned to their equilibrium values, i.e., to the values in year -1 .

The dynamics exhibited by the model gives support to the main tenets of the staple and the boom and bust theories, that is, periods of overproduction are followed by periods of underproduction. This is due to the slow and cyclical response of tobacco production (ECM) to increases in the bdt . This specific response provokes a cyclical behavior in tobacco prices that can not be detected with a simple univariate time series analysis. The

price of land, a less important variable in previous empirical analyses, now plays an important role. The residuals of the pl versus bdt regression contain relevant information about the rate of growth of tobacco production

V. Summary and Concluding Remarks

This paper uses a general econometric methodology to allow the empirical testing of the staple theory. The methodology is based upon recent developments in the theory of time series analysis, namely on the development of multivariate stochastic time series techniques adjusted to accommodate the presence of co-integration. To help interpret the results of the purely statistical analysis, the contemporary correlation among the noises of the multivariate stochastic ARMA model are seen as intra-year effects among the different variables.

The empirical implementation of this methodology focuses on the dynamic relationships among tobacco prices, British demand for tobacco, and land prices for the Chesapeake economy in the period 1676-1713. Empirical evidence in this paper strongly supports the staple theory and the boom and bust hypothesis. First, consistent with the staple theory, British demand of tobacco is exogenous and central to the transmission mechanisms of economic fluctuations. It neither receives lagged effects nor instantaneous effects from the other variables, while it affects both the price of tobacco and tobacco production. Second, and in agreement with the boom and bust hypothesis, the price of tobacco responds in a cyclical fashion to variation in the British demand because production conditions respond cyclically to variations in the British demand. Shocks in the British demand for tobacco lead to cyclical variations in production and, through production, on the price of tobacco. Third, and also in agreement with the boom and bust hypothesis, empirical results suggest that the British demand for tobacco affects the price of tobacco and tobacco production without feedback. The British demand for tobacco,

thus, is rigid (does not respond at all) with respect to tobacco prices.

The empirical evidence suggests that the staple and the boom and bust theories are not only the most sensible theories consistent with the data but also the only sensible theories consistent with the data. Alternative theories would require violation of either technical requirements or major departures from basic economics ideas.

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TABLE 1. Univariate Models

Series	Order of differentiation	MA(1) parameter	Residuals			
			Mean	s.d.%	Asymmetry	Kurtosis
$\hat{\epsilon}_{nPT_t}$	1	-	-.001 (.014)	8.7	.2	2.8
$\hat{\epsilon}_{nBDT_t}$	1	.67 (.12)	.026 (.031)	19.2	-1.9	7.4
$\hat{\epsilon}_{nPL_t}$	1	.51 (.15)	.012 (.022)	13.7	.2	3.6
$\hat{\epsilon}_{nPSL_t}$	1	.48 (.15)	.021 (.022)	13.6	-.2	2.3
						1703, 1705
						1700, 1706

Standard errors in parenthesis

TABLE 2. Cointegration analysis between $\hat{\epsilon}_{nPL}$ and $\hat{\epsilon}_{nBDT}$

1. Levels Regression
$\hat{\epsilon}_{nPL_t} = .35 \hat{\epsilon}_{nBDT_t} + ECM_t$
$ECM_t = .38 ECM_{t-1} + \epsilon_t$
$\epsilon_t \rightarrow i.i.d. N(0, .15)$
2. Error Correction Model
$\Delta \hat{\epsilon}_{nPL_t} = -.52 ECM_{t-1} + a_t$
$a_t \rightarrow i.i.d. N(0, .13)$

Standard errors in parenthesis

TABLE 3a. Multivariate Stochastic ARMA Model (MS)

AR Matrix	Series Vector	MA Matrix	Noise Vector
$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1-.48B & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} \Delta \epsilon_{nPT_t} \\ \epsilon_{CM_t} \\ \Delta \epsilon_{nBDT_t} \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 \\ .60B & 1 & 0 \\ (.30) & 0 & 1-.67B \\ & 0 & 0 & (.12) \end{bmatrix}$	$\begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \\ \epsilon_{3t} \end{bmatrix}$

Standard Errors in parentheses

TABLE 3b: Main statistics

Series	Mean	s.d.	Z	Asymmetry	Kurtosis	|Residuals| > 3 s.d.
ϵ_{1t}	-.001 (.014)	8.7	.2		2.8	
ϵ_{2t}	.005 (.024)	14.7	.4		3.2	
ϵ_{3t}	-.026 (.031)	19.2	-1.9		7.4	1703,1705

Standard errors in parentheses

TABLE 3c: acf and pacf functions of MS model residuals

Series	acf					pacf				
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ϕ_{11}	ϕ_{22}	ϕ_{33}	ϕ_{44}	ϕ_{55}
ϵ_{1t}	.14	-.07	-.33	-.27	.15	.14	-.09	-.31	-.22	.19
ϵ_{2t}	.08	.13	-.11	-.28	-.19	.06	.13	-.13	-.30	-.15
ϵ_{3t}	-.06	.22	.08	-.18	-.06	-.06	.21	-.06	-.25	-.06

 $\pm 2/\sqrt{58} = \pm .33$

TABLE 3d: ccf's among MS model residuals

ccf's	lags					Contemporaneous Correlations
	1	2	3	4	5	
$\epsilon_{1t} \rightarrow \epsilon_{2t}$	.00	-.27	.09	.15	.12	-.44
$\epsilon_{1t} \rightarrow \epsilon_{3t}$	.15	.20	.07	.27	.15	
$\epsilon_{2t} \rightarrow \epsilon_{3t}$	-.02	.23	.03	-.10	-.04	.36
$\epsilon_{1t} \rightarrow \epsilon_{3t}$	-.16	.00	-.08	-.03	.09	
$\epsilon_{2t} \rightarrow \epsilon_{3t}$	-.27	-.10	-.01	.27	.04	-.63
$\epsilon_{2t} \rightarrow \epsilon_{3t}$	.03	-.11	.30	.18	.24	

 $\pm 2/\sqrt{58} = \pm .33$

Figure 2
Excess supply vs BOT (rate of growth)
Impulse response function

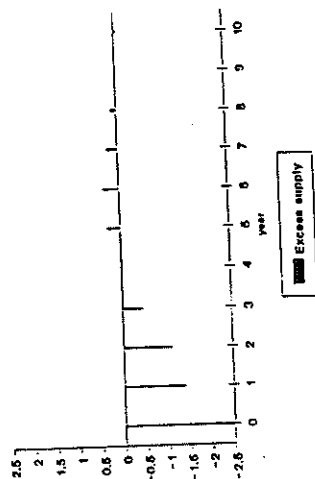


Figure 1
Production vs BOT (rate of growth)
Impulse response function

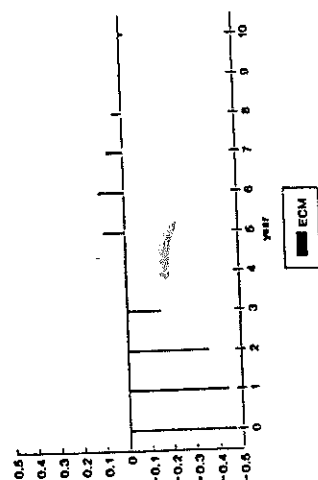


Figure 4
PL vs BOT (rate of growth)
Impulse response function

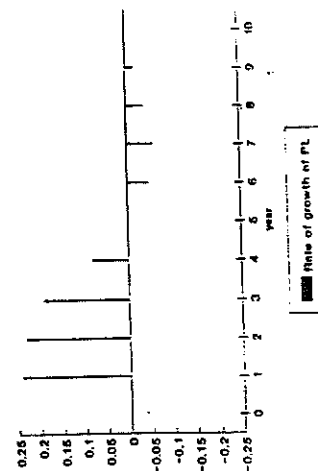
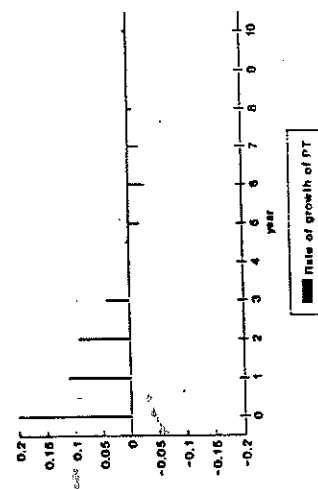


Figure 3
PT vs BOT (rate of growth)
Impulse response function



SERIE DE DOCUMENTOS DE TRABAJO DEL ICAE

- 9301: "Análisis del Comportamiento de las Cotizaciones Reales en la Bolsa de Madrid bajo la Hipótesis de Eficiencia". Rafael Flores de Frutos. Diciembre 1992.
- 9302: "Sobre la Estimación de Primas por Plazo dentro de la Estructura Temporal de Tipos de Interés". Rafael Flores de Frutos. Diciembre 1992.
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- 9304: "Tax Analysis in a Limit Pricing Model". Félix Marcos. Febrero 1993.
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